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Optimization of Combustion Behavior and Producer Gas Quality from Reclaimed Landfill Through Highly Densify RDF-Gasification

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Abstract

The growth in population, technology, and economy are resulting in the rapid increase of Municipal Solid Waste (MSW), which has a significant direct impact to the environment. MSW is generally disposed by landfill, which requires a lot of land space. Moreover, it is considered as a non-sustainable solution, by which only decomposable material is decayed where plastic and paper still remain inside. In order to provide the land space for recently large amount of waste, the old MSW need to be reclaimed and used as alternative fuel for sustainable disposal and converted into green and clean energy through gasification process. However, using an as-receive reclaimed product faces the challenges of combustion behaviour because it is non-homogeneous and loosens. This study discusses the improvement of the characteristics of the as-received reclaimed product by converting it into high density Refuse Derived Fuel (RDF). The surrogate reclaimed landfill RDF used has been made of waste plastic (polyethylene) and paper with a ratio of 75:25 %-wt. After densification by extrusion, RDF-5 has a density higher than 600 kg/m^3. The experiment was conducted in a laboratory scale downdraft gasifier by feeding surrogate RDF 10 kg/hr with the air flow rate 12, 15 and 18 Nm^3/hr, respectively. Charcoal was added as an additive at the same weight of RDF in order to increase the fraction of fixed carbon and improve concentration of producer gas. The influences of the additive on the producer gas concentration and combustion characteristics were investigated. Results showed highest CO% and LHV were affected by air flow rate of 12 Nm^3/hr at 22.02%-vol and 4.39 MJ/Nm^3, respectively, whereas highest H_2% was obtained with air flow rate of 15 Nm^3/hr. It was found that the densification of the reclaimed landfill and the mixing of the additive optimized the combustion behavior in terms of temperature distribution along the gasifier height and improved the producer gas quality.

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Keywords: reclaimed landfill, refuse-derived fuel, gasification, renewable energy

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1. Introduction

Petroleum fossil resources are limited in times and therefore are arraigned in environmental impact. At the same time, the increase in the world population is a crucial problem in terms of energy usage and environmental pollution. Municipal Solid Waste (MSW) has also rapidly increased due to the increase in the consumption of natural resources. This has caused a deficiency in sanitary landfill and the left being disposed in open dumpsites and being burned in an uncontrolled manner into the atmosphere. For a sustainable solution, the reclaiming of MSW from dumpsites to recover energy in terms of heat and electricity by thermal conversion should be prudentially considered. Gasification is a promising thermal conversion technology with a high energy output yield compared to conventional incineration [1]. In order to use the reclaimed landfill waste as fuel in the gasification process, RDF (Refuse-Derived Fuel) is the suitable form of feedstock. RDF-5 can be classified as high densified fuel by compression in several forms: pellets, briquettes, etc. The benefit of compression is that it doesn't only increase density but also easy to transport since the different location of landfill and the gasifier place [2,3].

The aim of this research was to study the characteristics of combustion behaviour and producer gas production with optimum operating conditions by using RDF-5 from reclaimed waste as feedstock for gasification. To ensure the uniformity of the physical and composition of the RDF, surrogate RDF was produced using the extrusion method. It contains waste plastic (High Density Polyethylene, HDPE) and waste newspaper with a ratio of 75:25 %-wt. to represent the forty-year-old reclaimed waste [2]. To increase the efficiency of the gasification, charcoal was fed into the bottom of gasifier with the same weight of RDF as the additive. Because, to conduct a gasification experiment using feedstock that contains high plastic (high volatile fraction) can generate a high temperature and damage the gasifier. Feeding some biomass or char into the reaction is beneficial to control the overall temperature and to maintain the gasification reaction due the high fraction of fixed carbon in charcoal. The downdraft gasifier was deployed in this experiment due to its high thermal efficiency and lower tar producing. Producer gas concentration, lower heating value, and distribution of the temperature inside gasifier were investigated in this study.

2. Materials and Experimental Methodology

2.1. Feedstock

Fig. 1. RDF-5 from Extrusion with heater at die

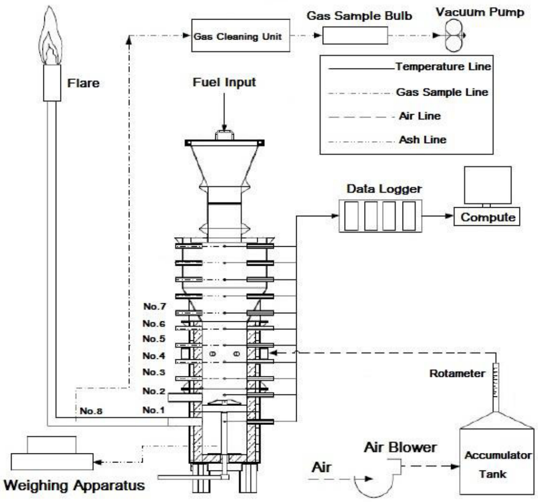

Fig. 2. Schematic diagram of the downdraft gasification system

The feedstock used in this study consisted of RDF and charcoal. The extruded RDF-5 was surrogate reclaimed landfill made from waste plastic (HDPE) and waste newspaper with a ratio of 75:25 %-wt. The RDF was prepared using a screw extrusion machine which was adapted from a conventional biomass briquetting machine [4] as shown the photo of the RDF-5 in Fig. 1. The mangrove wood charcoal was used as the additive to protect the blocking inside gasifier especially at throat position from melting of plastic. The melting can obstruct gas flow down from pyrolysis zone to reduction zone, therefore, reaction cannot continue. The chemical characteristics of the RDF-5 and mangrove wood charcoal used in this study were analyzed according to ASTM standard.

2.2. Experimental Methodology

The experiments were conducted in a 10 kg/h laboratory-scale downdraft gasifier. The system consists of a gasifier, hopper, air blower, rotameter, thermocouples, gas sampling unit, gas flare, weight apparatus, and data logger as demonstrated in Fig. 2. In order to start up the downdraft gasifier, 10 kg of charcoal was first introduced into the gasifier in the oxidation and reduction chamber. After the completed combustion of the charcoal, 10 kg of RDF-5 was fed into the gasifier. Simultaneously, air was supplied into the combustion zone of the gasifier as a gasifying agent at a constant flow rate which was controlled by rotameter. The air flow rate was set to be 12 Nm^3/hr, 15 Nm^3/hr and 18 Nm^3/hr. After the RDF was ignited and the gasification process began, the temperature of the combustion zone and the reduction zone raised until constant values. Three samples of producer gas were taken to analyze the producer gas composition and energy recovery from the gasification system. All zones of the gasification reaction were recorded for temperature from the start through the stable condition in which the gasification took place.

2.3. Method of analysis

Gas samples were analyzed using gas chromatography (GC) model GC-2014 with a TCD detector to analyze H_2, CO, CH_4 and CO_2. The producer gas concentrations obtained from the GC were used for analyzing the lower heating value of the different air flow rates. Lower heating value (LHV) is calculated by [6]:

$$LHV = \frac{126.36 \cdot CO + 107.98 \cdot H_2 + 358.18 \cdot CH_4}{1000} \tag{1}$$

where LHV is the lower heating value (MJ/Nm^3), CO, H_2 and CH_4 are the molar percentages of the producer gas composition.

3. Results and discussion

3.1 Feedstock analysis

The results of the experiment are find out and discuss for the optimum operation condition. To operate the downdraft gasifier, the feedstock have to be analysed to study the producer gas composition and combustion characteristics. Table 1 shows the chemical characteristics of the RDF-5 and mangrove wood charcoal.

The moisture content of the RDF-5 had a very low value at only 1.48 %-wt and the moisture content of the mangrove wood charcoal was 6.2 %-wt. The volatile matter of the RDF-5 was 94.112 %-wt, which was very high value because the RDF-5 consists of a higher amount of waste plastic (HDPE) with a mixing ratio of 75%-wt whereas the volatile matter of charcoal was only 25.2 %-wt. RDF-5 contained very low fixed carbon, it was low as 2.187 %-wt, in the other hand, fixed carbon of charcoal was high as 74.8 %-wt. The ash of RDF-5 was low as 2.337 %-wt and the ash of charcoal was 2.7 %-wt.

Table 1. The proximate and ultimate analysis of feedstock

Proximate analysis (%-wt)	RDF-5[1]	Mangrove wood[2] charcoal [5]	Ultimate analysis[2] (%-wt)	RDF-5	Mangrove wood charcoal [5]
Moisture content	1.48	6.2	C	75.38	77.53
Volatile matter	94.01	25.2	H	11.79	4.30
Fixed carbon	2.18	74.8	N	0.13	0.22
Ash	2.33	2.7	O	10.18	17.88
			S	0.04	0.05

[1] as received basis
[2] dry ash free basis

3.2 Temperature distribution

Temperature is one of the important factors in the gasification process because the gasification of each reaction zone needs the proper temperature range for the high quality of producer gas. The temperature distribution of each zone in a gasifier can be measured by using thermocouples installed at different positions along the gasifier, where T7 : drying zone, T6 : pyrolysis zone, T5, T4 : oxidation zone, T3, T2 : reduction zone, T1 : ash chamber and T8 : gas sampling port.

The results of the temperature distribution for the downdraft gasification process with RDF-5 and charcoal as feedstock with the air flow rate of 12 Nm^3/hr, 15 Nm^3/hr and 18 Nm^3/hr are shown in Figs. 4, 5 and 6, respectively. They show a quite stable temperature of thermocouple T1, T2 and T8. Those areas were the ash chamber zone, the reduction zone, and the producer gas sampling point, respectively. The temperature of the T4 was higher than T5 (air flow inlet position or combustion chamber) because gas flow downward faster than flame which flow upward as its natural behavior of downdraft gasifier [7]. The temperature contours of T4, T5 and T6 could be observed as fluctuating. This phenomenon in the downdraft gasifier is referred as the "bridging effect" [8]. It is occurred from collapse of fuel feedstock inside the gasifier in the operation after the steady state. Maximum temperature of each experiment could be measured at thermocouple T4. They were found at 1,049.5°C for air flow rate of 12 Nm^3/hr, 1,062.5°C for air flow rate of 15 Nm^3/hr and the highest was detected from air flow rate of 18 Nm^3/hr which was 1,181.3°C.

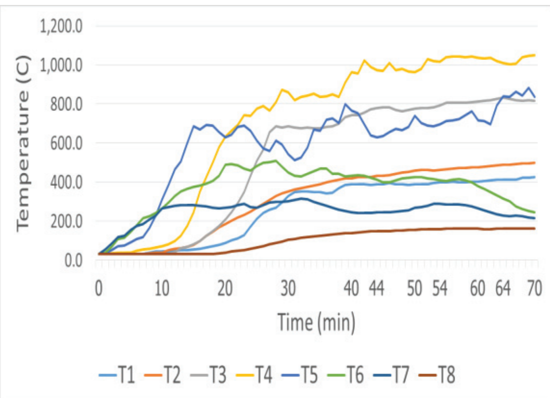

Fig. 3. Temperature distribution at the air flow rate of 12 Nm^3/hr

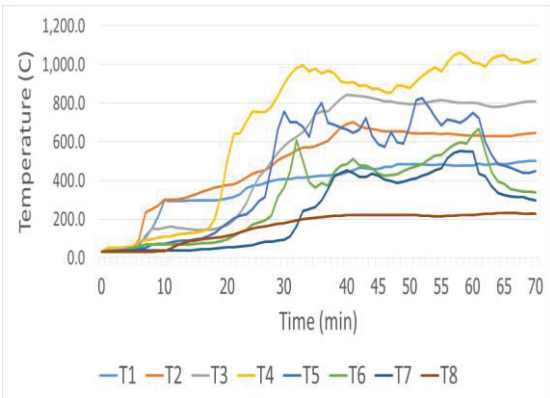

Fig.4. Temperature distribution at the air flow rate of 15 Nm^3/hr

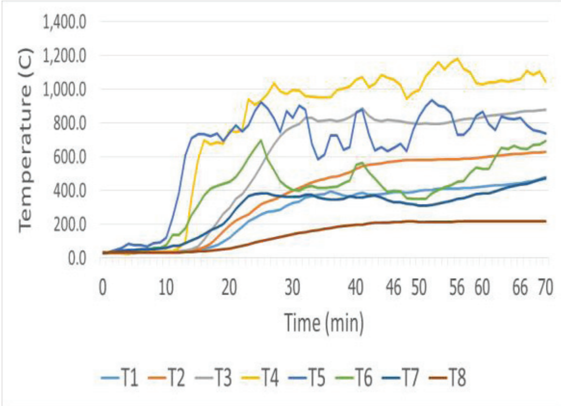

Fig. 5. Temperature distribution at the air flow rate of 18 Nm^3/hr

3.3 Effect of air flow and charcoal additive on producer gas quality

The air flow of the actual air supply indicates the oxygen feed in the combustion zone. The air flow is an important factor that influent in combustion behaviour and producer gas quality. In addition, physical characteristics and chemical property of the feedstock play important role in producer gas compositions. According to gasification rections, fixed carbon is an important factor for thermochemical reactions at the reduction zone in terms of producer gas quality.

Table 2. Producer gas composition at different air flow rates

Air flow rate	Producer gas composition (%-vol)				Lower heating value MJ/Nm^3
Nm^3/hr.	CO	CH_4	CO_2	H_2	
12	20.88	1.85	4.59	10.33	4.41
	21.93	1.37	3.89	9.82	4.32
	22.02	1.35	3.58	10.43	4.39
Average	**21.61**	**1.52**	**4.02**	**10.19**	**4.37**
SD.	0.63	0.29	0.52	0.33	0.05
15	17.96	0.95	4.51	10.49	3.74
	18.20	0.57	3.96	8.98	3.47
	16.90	1.38	4.29	11.92	3.91
Average	**17.69**	**0.97**	**4.25**	**10.46**	**3.71**
SD.	0.69	0.41	0.28	1.47	0.22
18	16.83	1.45	2.59	10.90	3.82
	19.77	1.11	3.33	9.19	3.88
	21.44	0.86	3.34	8.22	3.90
Average	**19.35**	**1.14**	**3.09**	**9.44**	**3.87**
SD.	2.33	0.30	0.43	1.36	0.04

According to Table 2, at air flow rate of 12 Nm^3/hr, the given high average LHV was 4.37 MJ/Nm^3, for the air flow rate of 15 Nm^3/hr the average LHV was 3.71 MJ/Nm^3, and for the air flow rate of 18 Nm^3/hr the average LHV was 3.87 MJ/Nm^3. To compare with the related literatures of downdraft gasifier using RDF-5 as feedstock [9], [10], [11], the given LHV was higher than other research. The feedstock consumption rate indicated that the air flow rate of 12, 15 and 18 Nm^3/hr had a feedstock consumption rate of 5.85, 7.06, and 8.00 kg/hr respectively. Carbon monoxide from three experiments were detected quite high, the highest CO was average 21.61%-vol obtained from air flow rate 12 Nm^3/hr. On the other hand, the average carbon dioxide percentages were quite low. These can be considered that CO_2 generated from combustion zone flew down through the layer of charcoal which firstly put inside the gasifier. CO_2 reacts with high carbon content (fixed carbon) in charcoal to generate CO by Boudouard reaction.

CONCLUSION

The output of reclaimed landfill can be used to prepare the RDF for use as fuel in thermal conversion for clean energy through downdraft gasification. By adding the additive of charcoal with high fraction of fixed carbon can provide the optimum operating condition of the 10 kg/hr downdraft gasifier in order to obtain high-quality producer gas. It has lower heating value of 4.41 MJ/Nm^3 with high CO concentration 22.02%-vol at air flow rate of 12 Nm^3/hr. The maximum H_2 has been obtained from air flow rate of 15 Nm^3/hr which was 11.92%-vol. The lower heating value was high enough to apply in other purposes e.g. internal combustion engine to recover green and clean energy in the form of electricity for ultimate use of reclaimed landfill.

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References

[1] The Waste Incineration Research Center, King Mongkut's University of Technology North Bangkok, 2006, The technology evaluation of energy production from municipal solid waste, JGSEE BM-T-Ws-019

[2] Somboon Chalermcharoenrat, Nuth Sirirermrux, Krongkaew Laohalidanond and Somrat Kerdsuwan. Optimization of the Production of Densified RDF from Reclaimed Landfill without Mixing Binding Agent Using Hydraulic Hot Pressing Machine. The 5th TSME International Conference on Mechanical Engineering (TSME-ICOME 2014).

[3] Knoef, H.A.M, Handbook Biomass Gasification. 2005, Netherland: BTG biomass technology group.

[4] A.B. Nasrin, A.N. Ma, Y.M. Choo, S. Mohamad, M.H. Rohaya, A. Azali and Z.Zainal. Oil Palm Biomass As Potential Substitution Raw Materials for Commercial Biomass Briquettes Production, American Journal of Applied Sciences 5 (3): 179-183, 2008, ISSN 1546-9239.

[5] P. Abdul Salam, S.C. Bhattacharya. A Comparative study of charcoal Gasification in two type of spouted bed reactors, Sciences Direct, Energy 31 (2006) 228-243.

[6] Maoyun He, Zhiquan Hu, Bo Xiao, Jianfen Li, Xianjun Guo, Siyi Luo, Fan Yang, Yu Feng, Guangjun Yang, Shiming Liu. Hydrogen-rich gas from catalytic steam gasification of municipal solid waste (MSW): Influence of catalyst and temperature on yield and product composition, International Journal of Hydrogen Energy, 34 (2009): 195-203.

[7] Kallis, K.X., G.A.P. Susini, and J.E. Oakey. A comparison between miscanthus and bioethanol waste pellets and their performance in a downdraft gasifier. Applied Energy, 2013. 101(January 2013): p. 333-304.

[8] Z. A. Zainal, A. Rifau, G. A. Quadir and K.N. Seetharamu. Experimental Investigation of a Downdraft Biomass Gasifier. Biomas and Bioenergy, 23 (2002): 283-289.

[9] Tada Uthaikiattikul, Somphot Cherdpong, Krongkaew Laohalidanond, Somrat Kerdsuwan. Exprimental study of RDF-gasification for power generation : University's RDF Model, AEC24. The Second TSME International Conference on Mechanical Engineering, 19-21 October, 2011, Krabi.

[10] Chart Chiemchaisri, Boonya Charnnok, Chettiyappan. Visvanathan. Recovery of plastic wastes from dumpsite as refuse-derived fuel and its utilization in small gasification system. Bioresource Technology 101 (2010) 1522-1527.

[11] Suthinee Hirunprasertsri, Suthep Buddee. Experimental study to obtain gas production condition from old landfill solid waste by using gasification process SWU Engineering Journal (2014) 9(1), 16-17.